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GEOPHYSICAL INSTITUTE

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UNIVERSITY OF ALASKA

Technical Report

THE EFFECT OF BAROMETRIC PRESSURE VARIATION ON THE "U.S.O." LONG-PERIOD SEISMOMETER

by

P.I.

Eduard Berg and Ronald Rasmussen

Contract numbers F-44620-68-C-0066 and F-44620-70-C-0031

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Project Title:	**Tectonic Movement, Deformation Release and Crustal Structure Studies in Alaska**
ARPA Order No.:	**292**
ARPA Program Code No.:	**9F10**
Project Scientist:	**Dr. Eduard Berg** **Geophysical Institute** **University of Alaska**
Telephone Number:	**907: 479-7373**

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THE EFFECT OF BAROMETRIC PRESSURE VARIATION ON THE "U.S.O." LONG-PERIOD SEISMOMETER

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ABSTRACT

The particular manner of mechanical construction of the Long-Period U.S.O. package is responsible for the pressure sensitivity of the LP-X component. The effect seems to be linear with pressure for periods larger than the seismometer period and short compared to the feedback signal time constant. Under the particular setting of the Gilmore (GLM) installation, a pressure induced displacement of the x component is $\frac{\Delta x}{\Delta p} = \frac{-13.8 m\mu}{\mu \text{ bar}}$ (without feedback).

Since the pressure induced displacements are considered as very undesirable noise for the instrument as either long period seismometer or as tiltmeter the borehole was pressure sealed and the effect removed. Records are presented to demonstrate the effect.

INTRODUCTION

Three "Unmanned Seismic Observatories" called briefly "U.S.O." have been obtained and installed in Central Alaska at the following sites:

MCK	63°44.02' N	148°55.95' W	610M (ground surface)
PAX	62°58.19' N	145°28.12' W	1034m (ground surface)
GLM (prelim)	64°59.24' N	147°23.34' W	722m (ground surface)

They form a tripartite network in Central Alaska and are included in the large aperture telemeter system (see Fig. 1 for location). Each observatory package contains 3-component short and long period seismometers. The short-period instruments are of the "Ranger" type (To=1 sec), the long-period instruments are of the Lamont-Lunar-Ocean Bottom type (To=15 sec) with feedback and remote-automatic leveling. They have been described in a special report (Sandia Corporation, 1968).

INSTALLATION OF INSTRUMENTS

The sites have been selected to form a tripartite tilt network and be useful for short and extreme long-period data recording and finally to permit telemetry back to the seismic laboratory. The instruments have been installed in boreholes with the help of the Sandia Corporation group that had put them together and tested. The bottoms of the holes are at the following depth below surrounding surface: GLM 15ft., PAX 38ft., MCK 28ft. GLM was installed in the late fall 1968 and operated in June 1969. PAX and MCK were installed in the summer of 1969 and operated some time thereafter.

MODIFICATION TO ORIGINAL EQUIPMENT

Since only the horizontal X component of the long-period set (LP-X) is of major interest in connection with the barometric pressure variation, only changes in the long-period electronics are described. It might be mentioned that all these changes have been carried out by the Sandia group. The transducer is a conventional capacitive type, with a carrier frequency of 3000 Hz. After amplification, the modulated carrier is demodulated. All the electronics involved to this point (excluding power supplies) is physically located with the instrument package inside the borehole. The demodulator output is fed through the feedback filter and a gain 1 amplifier. The output of this amplifier returns to the seismometer feedback coil (with-30 db) restoring the beam towards its center position. This output is also available for measurement (FB-X, Y or Z). The X and Y components can be used to measure tilts, the Z component to measure changes in gravity. The demodulator output (DEM-X, Y or Z) also goes to a filter and post-amplifier circuit.

The filter on each LP instrument (in the Sandia configuration) is peaking at 18 sec. which necessitates a feedback filter time constant of 1400 sec (10 MΩ and 22 μF). This system has been changed as follows:

1) The filter and post amplifier circuit has been replaced by the "Pomeroy Amplifier" which amplifier has a flat period response from 20 to 200 sec. (in the "Broad" position) with a gain of 115.

2) To accommodate this much broader filter response the feedback filter time constant was lengthened from the original 1400 sec to 6000 sec. (R = 10 MΩ, C = (22 + 90) μF).

The sensitivity of the LP instruments varies from instrument to instrument. Since calculations in the following chapter are based on the "Fairbanks" LP-X, (Sandia designation) the channel sensitivity assumed is 0.76 ±6.5% Volts/micron at the Sandia high gain output, or roughly 25 mV/micron at the demodulator output, before the feedback loop (-30db,time constant 6000 sec) becomes effective (for the sensitivity, see Sandia 1968, Table VII, p. 26).

SENSITIVITY OF THE LP-X COMPONENT TO ATMOSPHERIC PRESSURE VARIATIONS

The feedback outputs were connected at the stations to the FM telemeter modules (range ± 2.5 Volts) IRIG channels 1 through 7 were used. The signals were transmitted either by radio links or later by phone lines plus radio links and discriminated at the Geophysical Institute's terminal in a 1 to 1 manner (a +1 Volt input signal producing a +1 Volt output signal).

It was first found that the telemeter link, including the recording equipment, produced a 24 hour period with an amplitude of up to 100 mV p-p in the summer (see Fig. 2 for a similar variation at PAX). This was eliminated by disconnecting the VCO input from the feedback signal and grounding the same VCO input for 1 to 3 minutes every hour, so that hourly values with the corrected "0" position could be obtained. The variation was probably due to temperature variation at the stations. In MCK, where the electronics (VCO'S) are housed in a thermostatically controlled temperature environment, this effect could not be found.

The next observations, after the initial stabilizing period, was that the feedback signal showed much higher variation on the X component than on the Y component (see Fig. 2 and 3, GLM-X and Y). Also occasional recording of the LP-X and Y traces (after the Pomeroy amplifier) showed usually much higher "background" noise on the X component (see Fig. 4A, B). However it was not until November 1969 when we recorded MCK and plotted all data together (see Fig. 5) that the X component was definitely identified as responding to some unknown source. The telemeter system, the electronics and tectonicly generated tilts were ruled out, because the transmission channels were independent; phoneline-radio or radio-phoneline-radio links for each station and distances between stations (see Fig. 1) and/or orientation of the borehole package axis (GLM-X to North, PAX and MCK-X to East) as well as location with respect to Alaskan tectonic features made a common source for real tilts highly unlikely.

Then the mechanical construction was scrutinized: the X component leveling is achieved by leveling the outer gimbal ring. See Fig. 6 A, B for a picture of the outer gimbal ring and its drive motor; see Fig. 7 giving the layout of the horizontal components, associating X with the outer gimbal ring (this was taken from the Teledyn, Earth Science Division Engineering Report No. 615-1266-002, dated 28 January 1966). So only a tilt of this outer gimbal ring with respect to the axis of the borehole package could be blamed for the large variations observed. A tilt of this ring can be obtained by compressing or stretching the frame member holding the ring (the arm of the leveling drive remaining at constant length). The only force that can compress (or stretch) the frame, including the outside protective shell, is a pressure variation on the assembly, because this assembly is sealed pressure tight with 2 large "O" rings. If the exact cross section of the two frame members and the outer shell were known, the tilts resulting from such a variation could be calculated. The long-term atmospheric variations are of the order of 100 m bars or $100/gr/cm^2$; the total effective surface is the surface cross section of the instrument package (10 inch diameter) and the compression of steel is of the order of 4.6×10^{-7} per kg/cm^2 pressure increase. Since the outer shell plus frame section is relatively small compared to the total effective cross section of the package, these figures seem to indicate the right order of magnitude. In addition, the lever arm (distance from the gimbal ring rotation axis to the level drive attachement) is about a factor of 3 to 4 shorter than the distance from the bottom plate to the rotation axis (the length of which is variable with pressure) so that the tilt (as expressed in radians) are amplified by that factor.

In order to obtain a "scale" factor, the hourly barometric pressure values were obtained from the ESSA Weather Bureau at the Fairbanks International Airport and compared to the hourly values of tilt at the GLM station. Figure 4C shows a few minutes recording from the infrasonic array element located at the International Airport. No coherence can be expected with the Gilmore X at the same time (Fig. 4A). Since the infrasonic array element is in a low wind area, and GLM on top of a hill , an increase in amplitude of about a factor of 2 does not seem unreasonable in this frequency band. It was judged from the comparison that the distance between the two sites was insignificant for the long term variations.It also should be mentioned that 2 layers of about 5 inch foam rubber (each) were present when the measurements were made for GLM. In PAX a hard foam plug had been cast, but was not air tight along the casing because the casing was too cold for the foam to perform its normal binding. In MCK the hole was only covered with some wood and dirt. On the other hand when the outside shell is tied to the package, the gimbal ring support member will be under tension the outer shell under compression. The total barometric pressure effect might therefore depend also on the amount of tightening of the outer shell, and therefore be somewhat different for each package.

PRESSURE-INDUCED POSITION CHANGE OF X AXIS TRANSDUCER

A. Direction (refer to Figs. 6A, B, 7)

A pressure increase compresses the frame and outer shell but the length of the releveling drive arm is unchanged. Therefore the outer gimbal ring tilts towards the + X direction (+ X side down, - X side up), therefore the X mass moves in the + X direction corresponding to a ground motion in the - X direction generating a negative signal out of the DIN-X and FB-X outputs as long as the seismometer can follow (for all periods > 15 sec).

B. Calculation for CLM pressure sensitivity (with two 5 inch foam rubber plugs present) (see Fig. 5).

Δ Pressure 27 November 69 12^{H} 29.140 inch mercury

29 November 69 00^{H} 28.210 inch mercury

$\Delta P = -0.930$ inch mercury

Δ Tilt 27 November 69 12^{H} 11.00 Div.

29 November 69 00^{H} 18.25 Div.

$\Delta T =$ 7.25 Div, 1 Div = 50mV, 220mV $\simeq$ 1 secarc (See appendix for derivation)

$$\Delta T = 7.25 \text{ Div} \times \frac{50\text{mV}}{\text{Div}} \; \frac{1}{\frac{220\text{mV}}{\text{arc sec}}} = 1.645 \text{ sec arc}$$

This is taken <u>at the feedback</u> output.

$$\frac{\Delta T}{\Delta P} = \frac{-1.64 \text{ sec arc}}{0.930 \text{ inch Merc.}} \simeq -1.77 \frac{\text{sec arc}}{\text{inch Merc.}}$$

DISPLACEMENT

$$\Delta X_F = 7.25\ \text{mV} \div \frac{50\ \text{mV}}{\text{DSV}} \times \frac{1}{\frac{25\ \text{mV}}{\mu}} = 14.5\ \mu \qquad \underline{\text{AFTER FEEDBACK}}$$

without feedback, or in the <u>seismic period range</u> (for a feedback factor of 30)

$$\Delta X = 14.5 \times 30\ \mu \approx 435\ \mu$$

<u>pressure induced displacement</u> in seismic spectrum before the feedback becomes effective (6000 ≥ T ≥ 15 sec)

$$\frac{\Delta X}{\Delta P} = \frac{\pm 435\ \mu}{0.930\ \text{inch Merc.}}$$

$$\frac{\Delta X}{\Delta P} = \frac{\pm 435\ \mu}{0.930\ \text{inch Merc.}\cdot \frac{3.39 \times 10^{-2}\ \text{bar}}{\text{inch Merc.}}} \approx \frac{\pm 138.10^{2}\ \mu}{\text{bar}}$$

$$\frac{\Delta X}{\Delta P} = \frac{\pm 13.8\ \text{m}\mu\ \text{(displacement)}}{\mu\text{bar (pressure)}} \quad \text{without feedback}$$

<u>demodulator output</u> sensitivity to pressure (6000 sec ≥ T ≥ 15 sec)

$$\frac{\pm 13.8\ \text{m}\mu}{\mu\ \text{bar}} \cdot \frac{25\ \text{mV}}{\mu} = \frac{\pm 0.345\ \text{mV}}{\mu\ \text{bar}} \quad \text{without feedback}$$

output after Pomeroy Amplifier

gain 115 (20-200 sec)

$$\frac{\Delta V}{\Delta P} = \frac{\pm 0.345\ \text{mV}}{\mu\ \text{bar}} \times 115 = \frac{\pm 39.7\ \text{mV}}{\mu\ \text{bar}}$$

COMMENTS

The difference in "noise" level between the X components (CLM, MCK) and the others on Fig. 4A and B is striking. The probable reason for PAX X only showing the longer-period noise is that the hard foam plug has a slow leak. Figure 4C, a recording of one of the infrasonic array elements near the Fairbanks airport, is put in for comparison for the same date and covering about 14 minutes of the recordings of Figures 4A, B. The peak-to-peak amplitude on the infrasonic record is probably between 15 and 20 μ bar (clipped on the record) obtained in a rather calm area.

The amplitude of the GLM X trace corresponds to about $1.5V \times \frac{1\ \mu bar}{40mV} \simeq 38\ \mu bar$. Figure 8 shows a longer-type barometric pressure oscillation (probably gravity waves) at MCK, situated in the Alaska Range. For comparison, Figures 9 and 10 depict two earthquakes after the GLM borehole has been pressure sealed, and show the low noise level on X.

CONCLUSIONS AND SUGGESTIONS

In conclusion it can be said that the LP-X component of the USO package forms an excellent microbarograph and barograph with a response from 15 sec to DC if there is no earthquake recorded.

If the package were to be rebuilt we suggest separating the frame members holding the instrument package from the outside protection. This can be achieved so that the outside shell with its bottom plate does not mechanically connect to the plate at the bottom end of the frame members. The latter plate holds the leveling drive motor and if not isolated, will be responsible for transmitting atmospheric pressure variations.

APPENDIX

TILT OF A HORIZONTAL PENDULUM

If a simple horizontal pendulum has a length l, with its axis of rotation perpendicular to the vertical, and initially at "o" position, a tilt of the vertical will produce an excursion X for a tilt of $\frac{X}{l}$ radians. For a pendulum with only a small angle between the vertical and the axis of rotation, and corresponding free period T, the equivalent length of the simple pendulum is given by:

$$l = \frac{T^2 g}{4\pi^2} \quad \text{Where } g = \text{earthgravity } (981\text{cm/sec}^2)$$

For a 15 sec pendulum the equivalent length is 57.3 meters. A 1µ displacement recorded at the transducer of a 15 sec pendulum therefore corresponds to a tilt of $\frac{10^{-6}\text{m}}{57.3\text{m}}$ radians or 1.745×10^{-8} radians. Since 1 sec arc = 4.85×10^{-6} radians, a 1 sec arc tilt produces $\frac{4.85 \times 10^{-6}}{1.745 \times 10^{-8}}\,\mu$ = 278 µ displacement on the transducer. The feedback reduces this displacement by a factor of 31.6 (30db), 1sec arc tilt produces therefore 278µ/31.6 or 8.80 µ displacement after feedback.

With a demodulator output of 25mV/u this finally gives

220 mV signal / sec arc tilt (after feedback)

if the tilt is in the direction perpendicular to the plane containing the vertical axis and the axis of rotation.

REFERENCES

Sandia Laboratories, U.S.O. (unattended seismological observatory, final evaluation report); SC-M-68-60, April, 1968.

Berg, Eduard; Sperlich, Norbert; and Feetham, William; "Large Aperture Seismic Telemetering System for Central Alaska"; Scientific Report, UAG R-188, Geophysical Institute, University of Alaska, May 1967.

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FIGURE CAPTIONS

1) Seismic network

2) GLM, PAX Tilts 30 July to 8 August, 1969

3) GLM-Tilts June 15 to June 28, 1969

4) A and B, GLM, PAX, and MCK Barometric Pressure noise on X components

   C. Microbarograph - Infrasonic recording at Fairbanks

5) Tilt on X components and Barometric pressure at Fairbanks International Airport

6) A and B, Instrument package

7) Layout of horizontal Seismometer components (Top View)

8) Typical Barometric effect on MCK-X

9) GLM-X noise background after the borehole was sealed. (The coupling between the three components has since been removed.)

10) GLM-X noise background (Coupling between Amplifiers removed.)

11) Suggested changes in the mechanical arrangement of the instrument package

Fig. 1

SEISMIC STATIONS

GEOPHYSICAL INSTITUTE, UNIVERSITY OF ALASKA

TELEMETER STATION

BOREHOLE STATION WITH TILT RECORDING

FOR SALE BY U. S. GEOLOGICAL SURVEY FEDERAL CENTER, DENVER, COLORADO OR WASHINGTON 25, D. C.

Fig. 1. Seismic stations

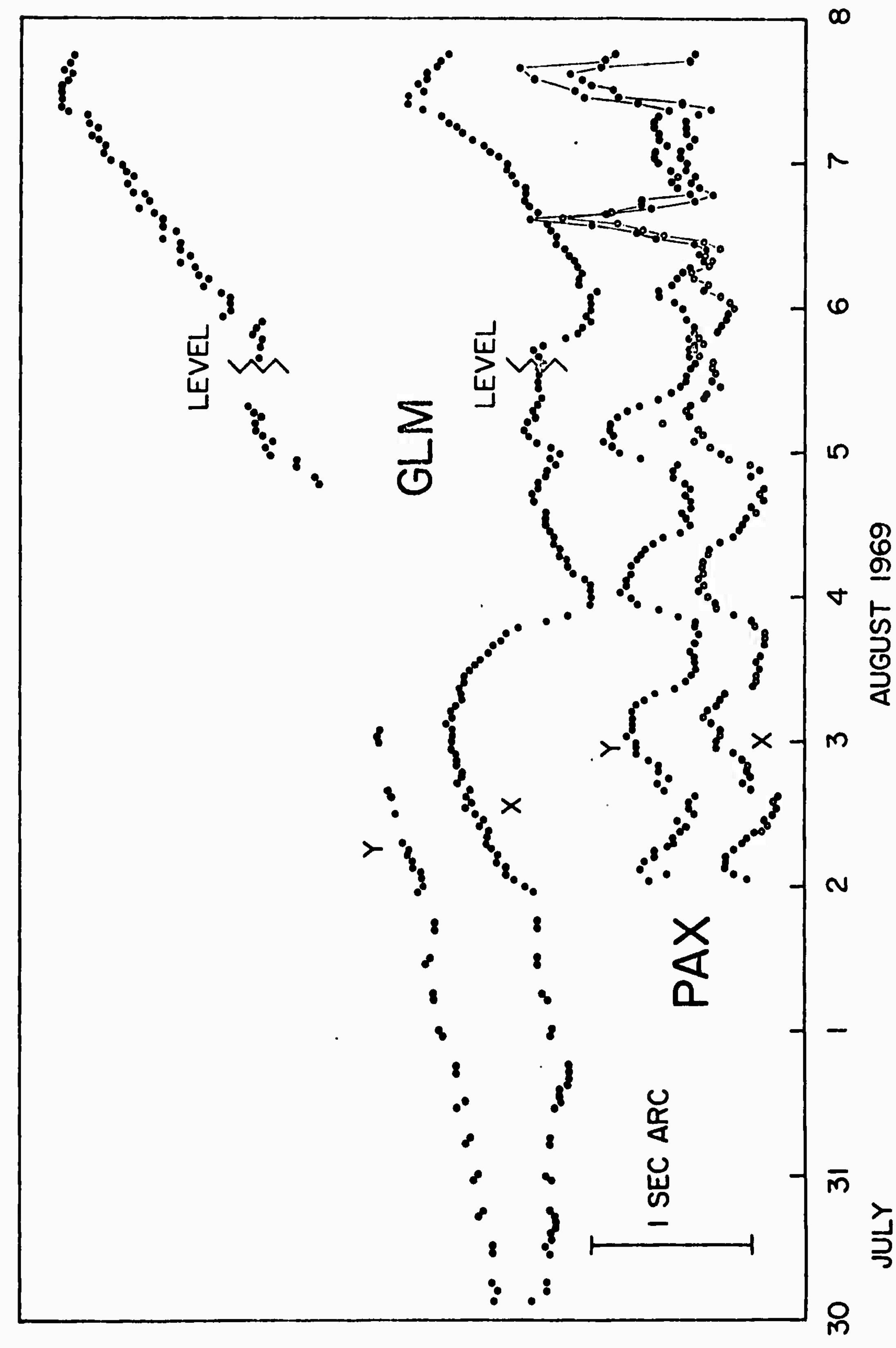

LEVEL
LEVEL
GLM
PAX
Y
X
Y
X
1 SEC ARC
30
31
1
2
3
4
5
6
7
8
JULY
AUGUST 1969

FIGURE 2

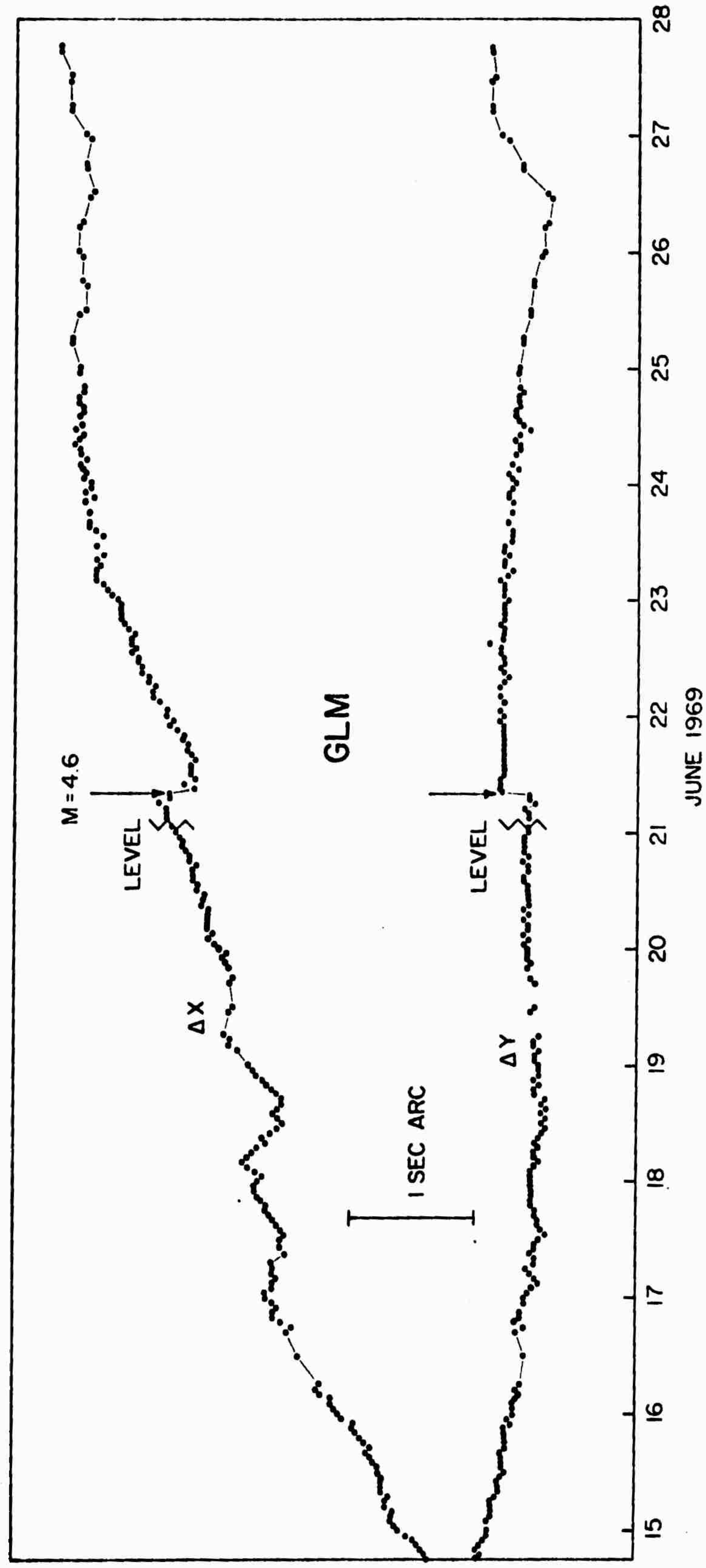

GLM
ΔX
ΔY
LEVEL
LEVEL
M=4.6
1 SEC ARC
JUNE 1969
15
16
17
18
19
20
21
22
23
24
25
26
27
28

FIGURE 2

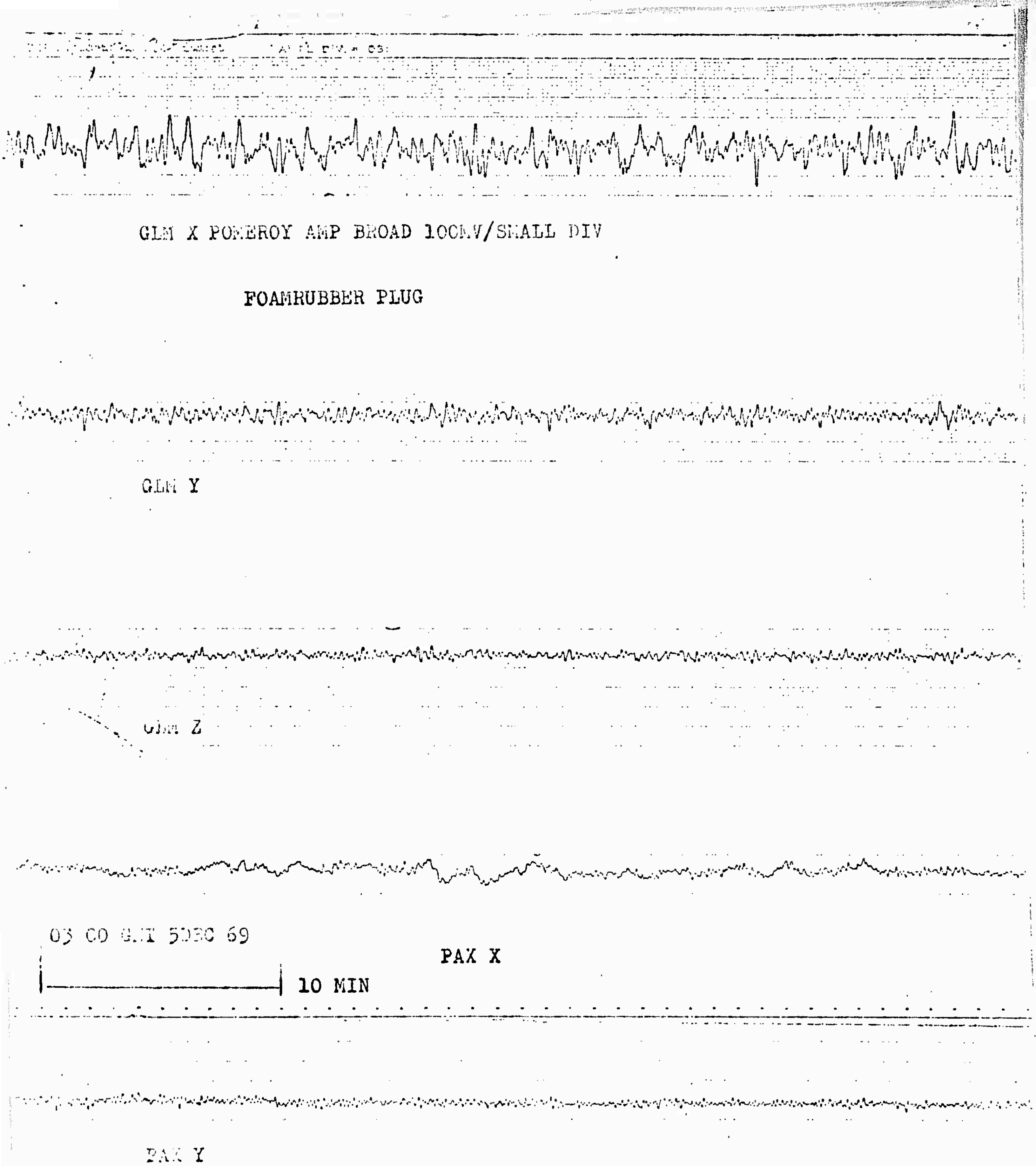

GLM X POMEROY AMP BROAD 100MV/SMALL DIV
FOAMRUBBER PLUG
GLM Y
GLM Z
03 00 GMT 5DEC 69
PAX X
10 MIN
PAX Y

FIGURE 4A

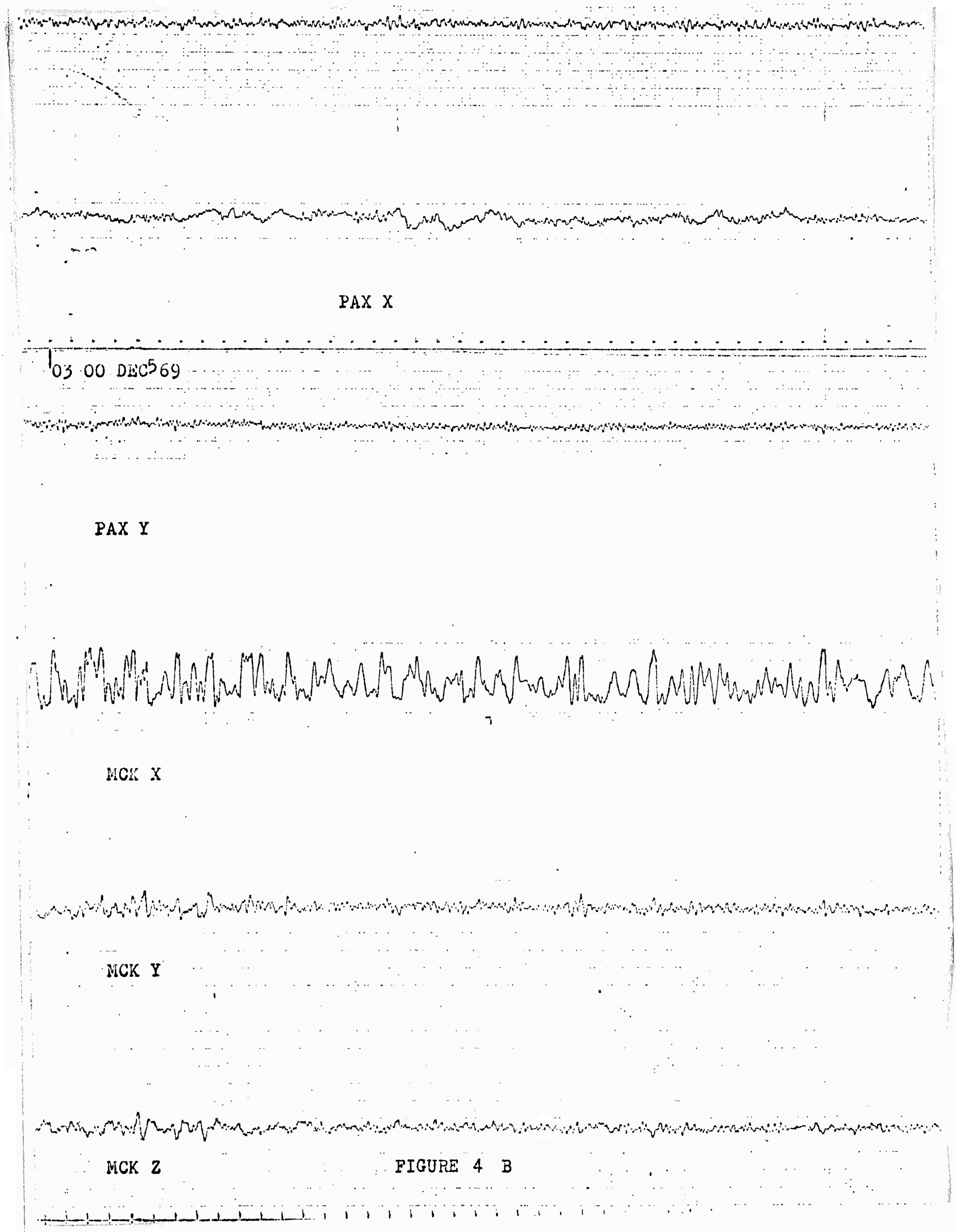


FIGURE 4 B

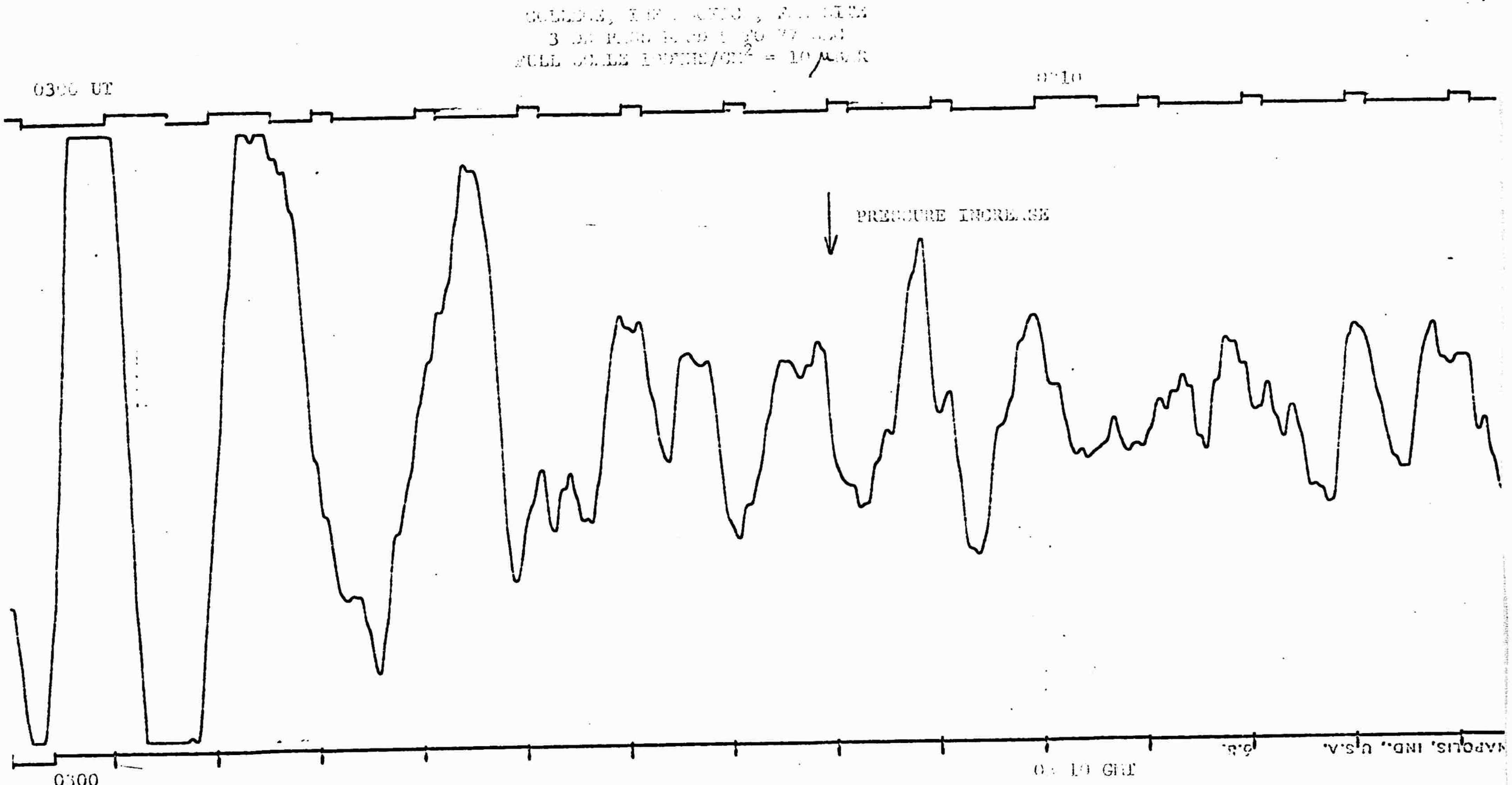


FIGURE
4 C

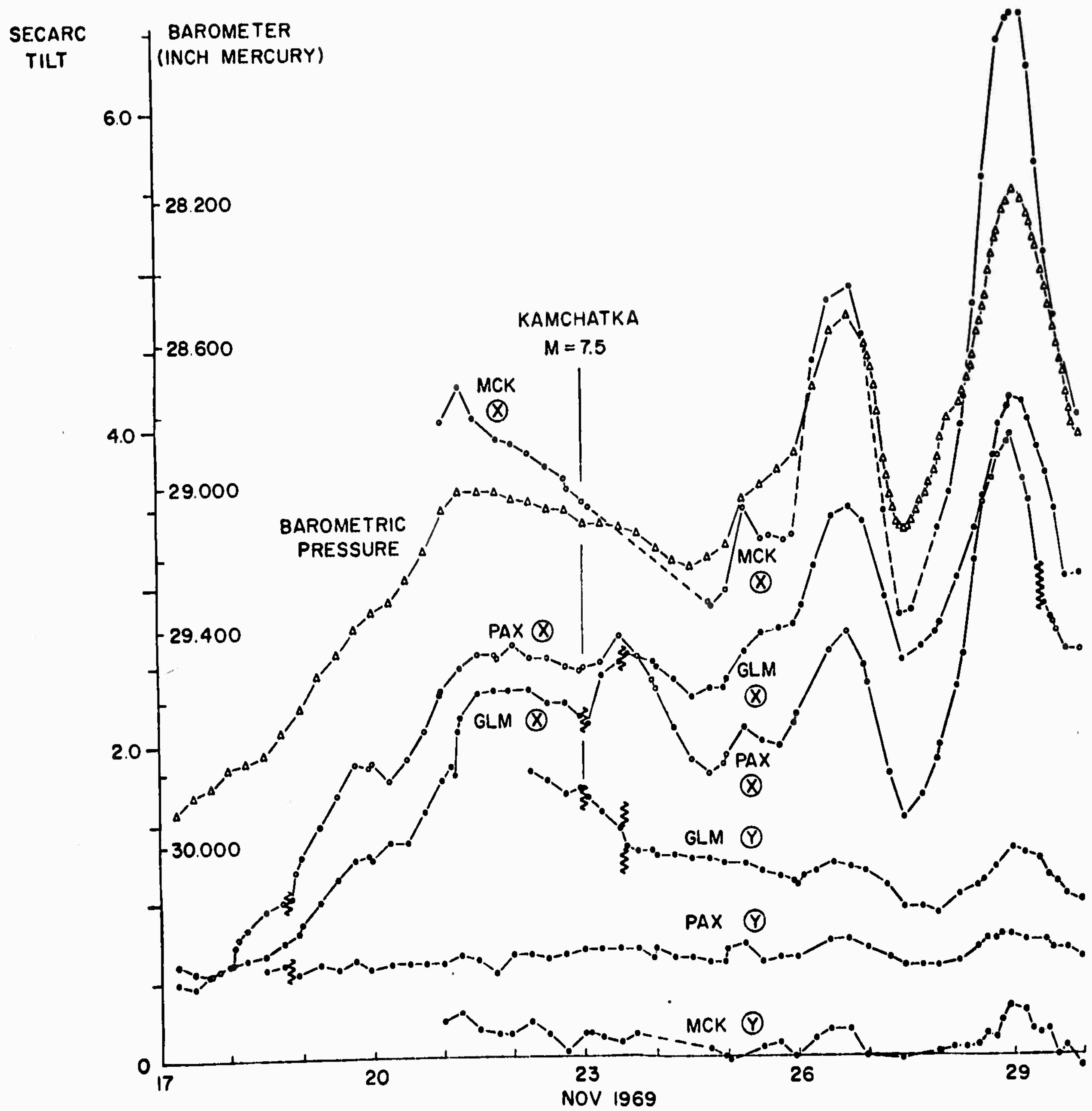

SECARC TILT
BAROMETER (INCH MERCURY)
6.0
4.0
2.0
0
28.200
28.600
29.000
29.400
30.000
KAMCHATKA M = 7.5
MCK Ⓧ
BAROMETRIC PRESSURE
PAX Ⓧ
GLM Ⓧ
GLM Ⓨ
PAX Ⓨ
MCK Ⓨ
17
20
23
26
29
NOV 1969

FIGURE 5

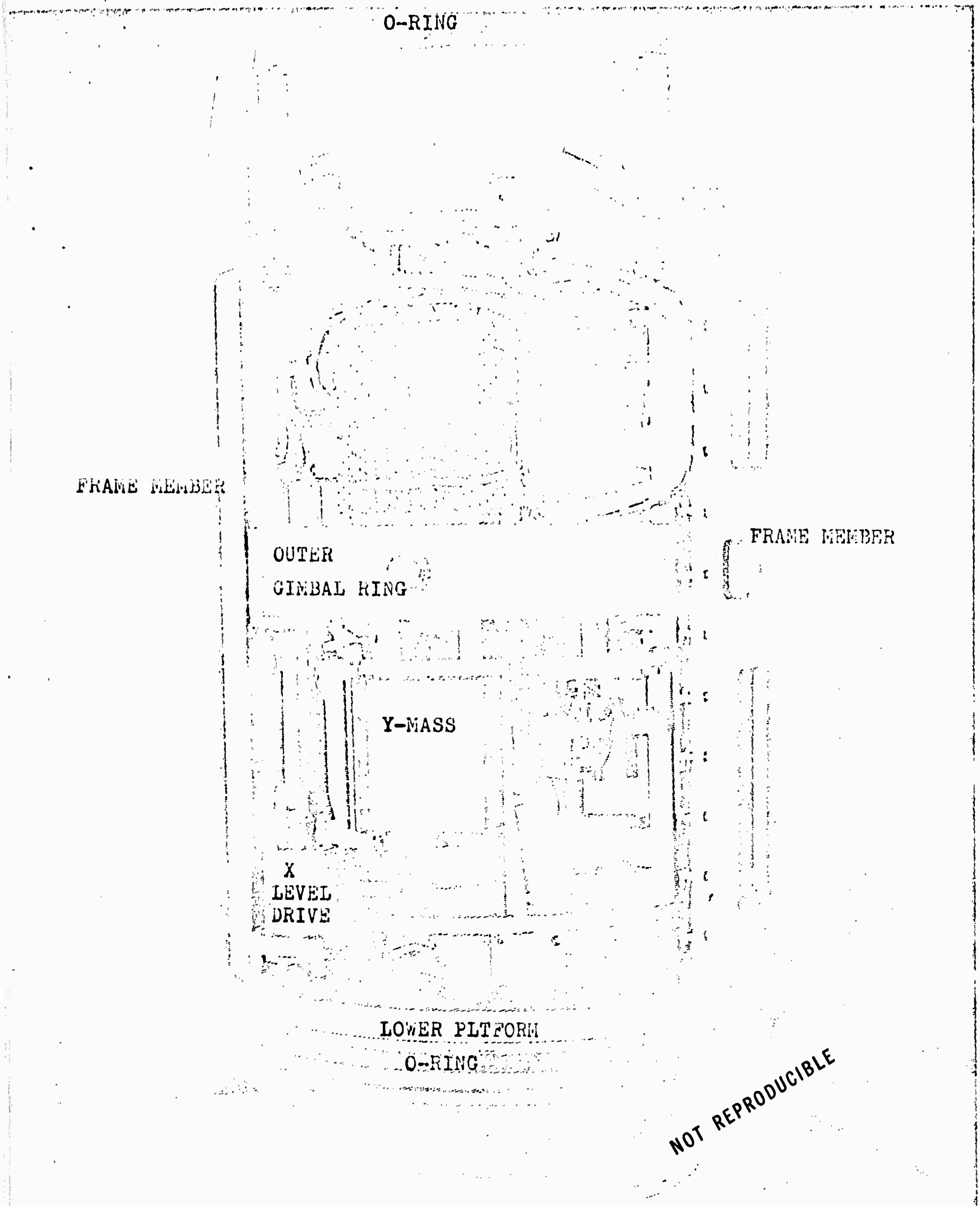

O-RING
FRAME MEMBER
FRAME MEMBER
OUTER
GIMBAL RING
Y-MASS
X
LEVEL
DRIVE
LOWER PLTFORM
O-RING

FIGURE 6 B

2. POLARITY CONVENTIONS

The following polarity conventions were used for the design and testing of the system.

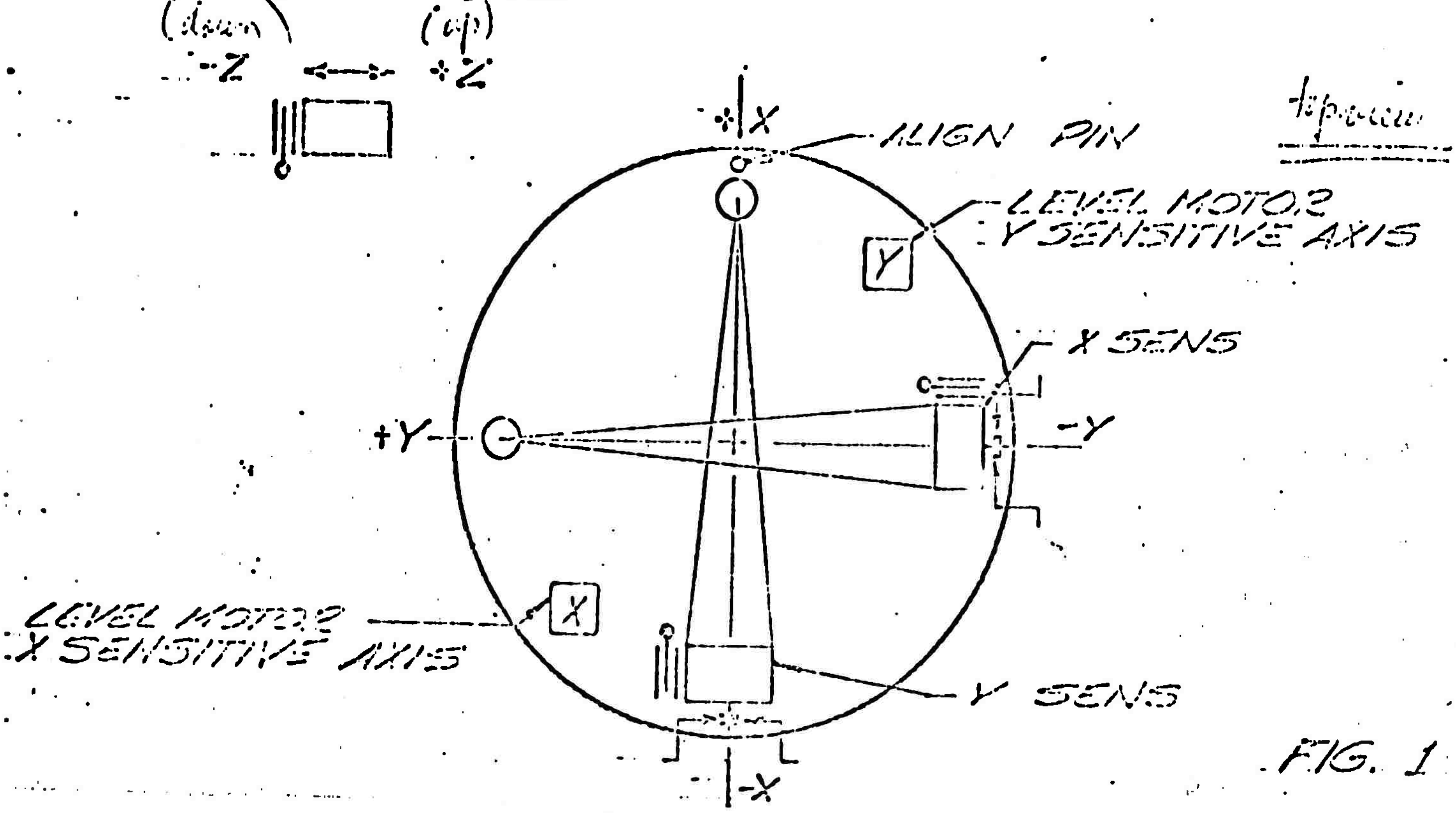


FIG. 1

Earth moves +, case moves + and mass moves toward -X, -Y, and -Z causing a positive (+) voltage at recorder. A positive (+) voltage from feedback filter to coil causes masses to move toward +X, +Y, & +Z.

Negative (-) calibration voltage causes masses to move toward -X, -Y and -Z producing a positive (+) output voltage at recorder.

Positive (+) voltage output causes -X, and -Y corners to rise (or raising vertical) moving masses toward +X and +Y and +Z causing a negative (-) voltage output.

FIGURE 7

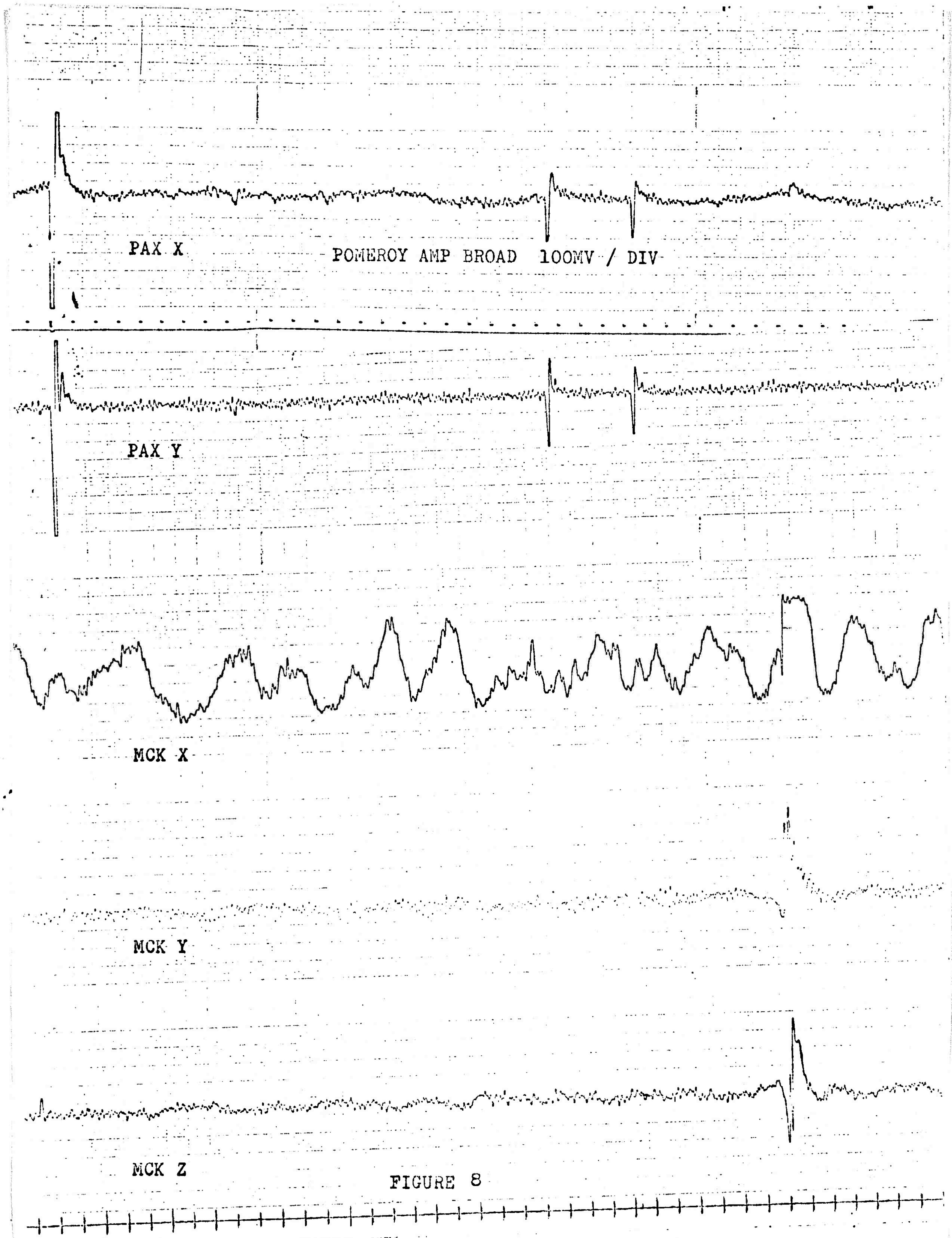
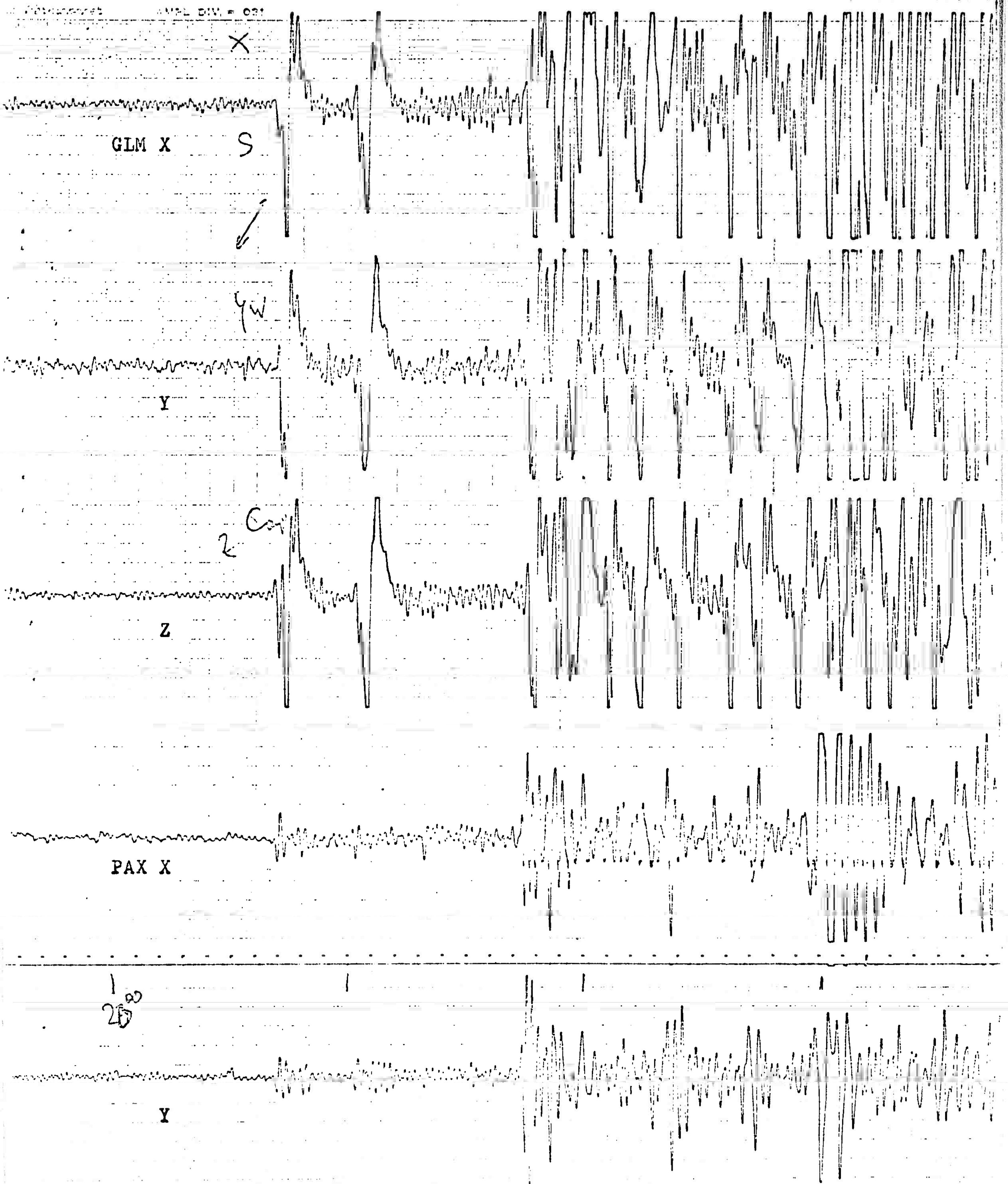


FIGURE 8

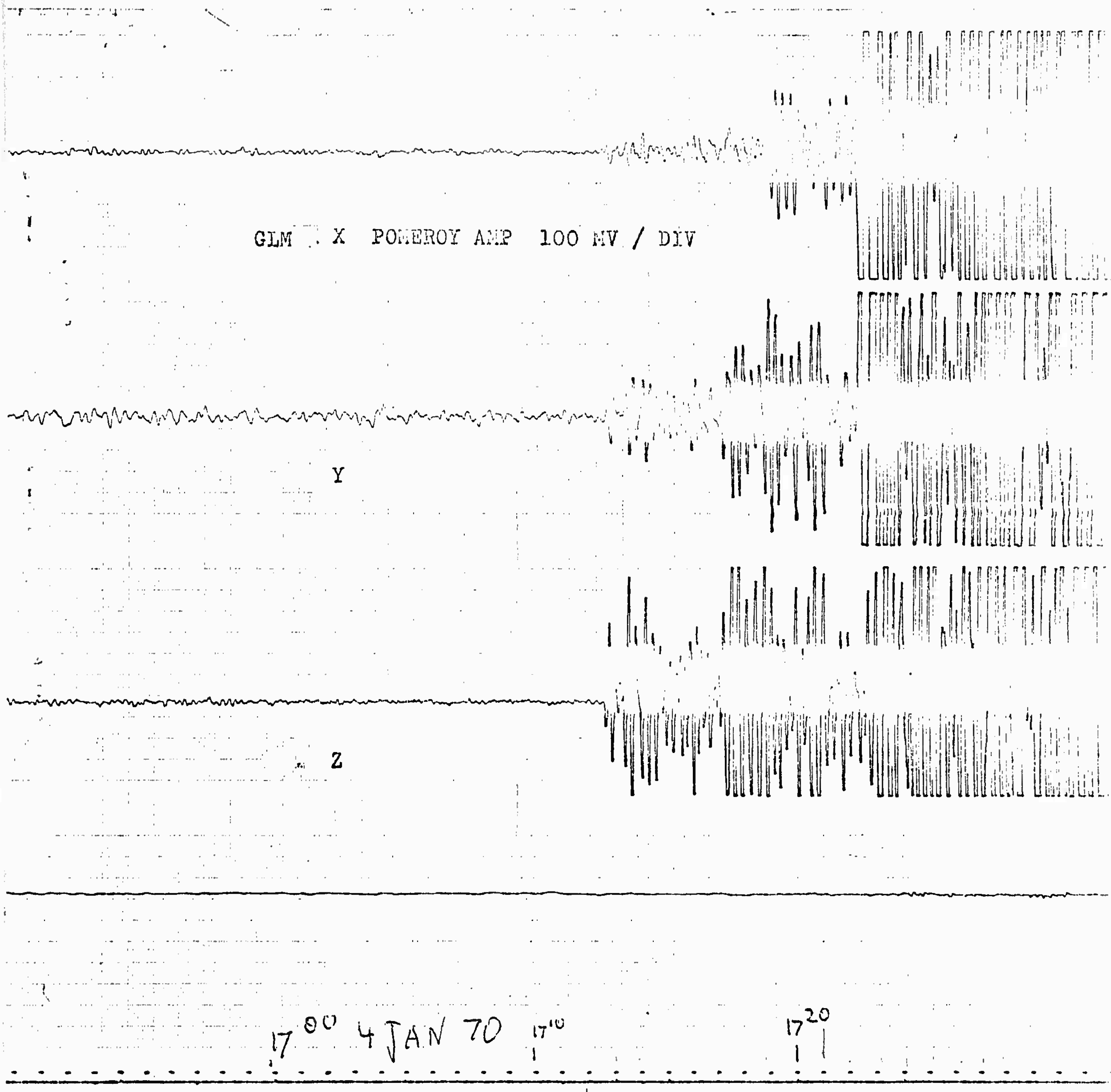


10 Dec 69

POMEROY AMP BROAD 100 MV / DIV

GLM BOREHOLE SEALED

FIGURE 9



USCGS EPICENTER 25N 102E
ORIGIN TIME 170042
MAG. 8.0

FIGURE 10

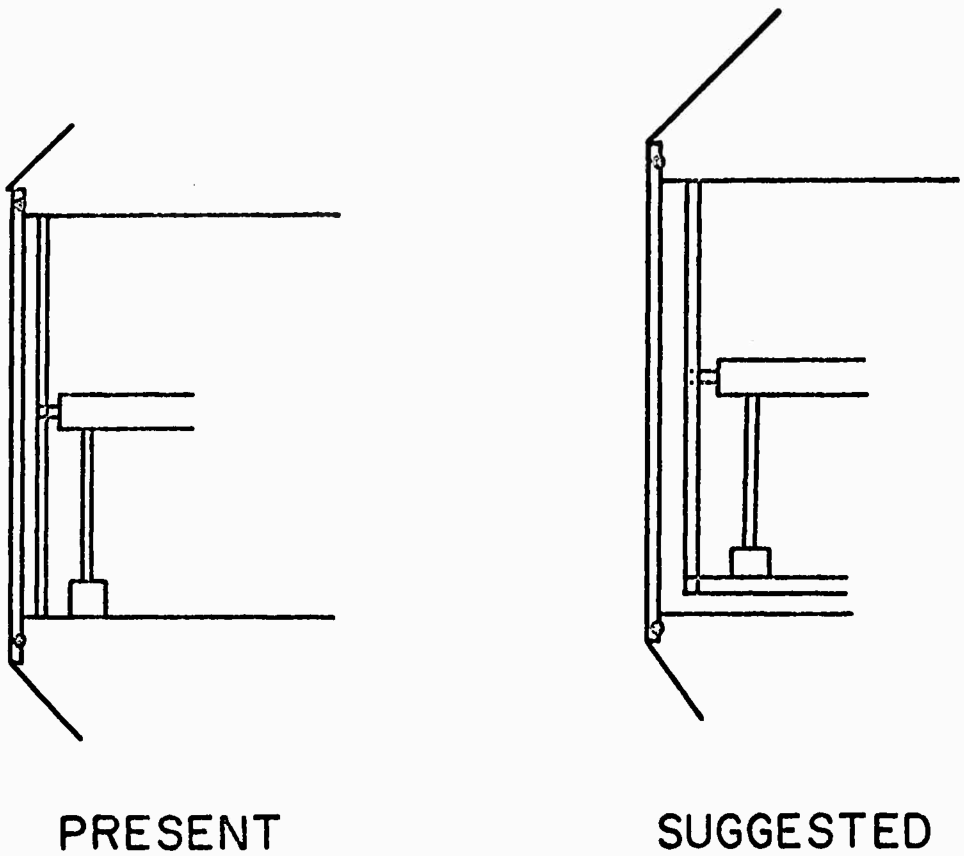


FIGURE 11

UNCLASSIFIED

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5. AUTHOR(S) (First name, middle initial, last name)

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Since the pressure induced displacements are considered as very undesirable noise for the instrument as either long period seismometer or as tiltmeter the borehole was pressure sealed and the effect removed. Records are presented to demonstrate the effect.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Alaska						
Barometric Pressure effect on U.S.O. Long-Period seismometer						
Sealed borehole						
Microbarograph						

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Security Classification